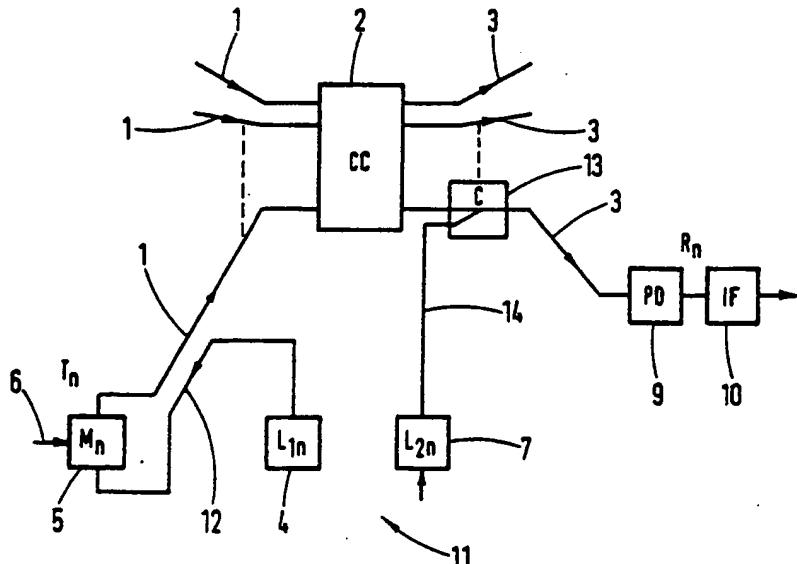




INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁴ : H04Q 11/02, H04B 9/00 H04J 15/00	A1	(11) International Publication Number: WO 86/ 04205 (43) International Publication Date: 17 July 1986 (17.07.86)
(21) International Application Number: PCT/GB86/00017		(74) Agent: WOLFF, Eric; Intellectual Property Unit, British Telecom, 151 Gower Street, London WC1E 6BA (GB).
(22) International Filing Date: 10 January 1986 (10.01.86)		
(31) Priority Application Number: 8500635		(81) Designated States: AT (European patent), BE (European patent), CH (European patent), DE (European patent), FR (European patent), GB (European patent), IT (European patent), JP, LU (European patent), NL (European patent), SE (European patent), US.
(32) Priority Date: 10 January 1985 (10.01.85)		
(33) Priority Country: GB		
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(54) Title: OPTICAL NETWORKS



(57) Abstract

An optical network comprises a plurality of transmitting (T_n) and receiving (R_n) terminals; and cross-coupling means (2), the transmitting (T_n) and receiving (R_n) terminals being optically coupled with the cross-coupling means whereby modulated carrier signals transmitted from each transmitting terminal (T_n) are fed to each receiving terminal (R_n) via the cross-coupling means (2). A plurality of first sources (4, 7) of optical signals are grouped together remotely from and optically coupled with the transmitting (T_n) and receiving (R_n) terminals to supply carrier signals and tuning signals to the transmitting and receiving terminals respectively.

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OPTICAL NETWORKS

The invention relates to optical networks comprising a plurality of transmitting and receiving terminals; cross-coupling means, the transmitting and receiving terminals being optically coupled with the cross-coupling means whereby modulated carrier signals transmitted from the transmitting terminals are fed to the receiving terminals via the cross-coupling means; selection means associated with each receiving terminal to select the modulated carrier signal to be received; and a plurality of first sources of optical signals optically coupled with the transmitting terminals to supply carrier signals to the transmitting terminals. Such optical networks are hereinafter referred to as of the kind described.

A simple form of optical network of the kind described includes an optical source (typically a laser) and a modulator at each transmitting terminal and a second optical source together with homodyne or heterodyne detecting apparatus at each receiving terminal. The optical sources associated with the transmitting terminals each provide carrier signals with different wavelengths which are modulated by an information signal and then transmitted to the cross-coupling means. This distributes the received modulated carrier signals equally between all receiving terminals. In order to receive a transmitted signal, the optical source associated with a receiving terminal is tuned appropriately.

A practical difficulty of building a network of the kind described above is that each laser associated with a transmitter must be referenced to the others to prevent cross-talk interference. Thus, if one carrier signal laser were to drift not only would the receiving terminal have to follow it, but beyond certain limits it would cause interference with other channels. Clearly it is

very difficult to reference this larg number of optical sources.

In accordance with the present invention, in an optical network of the kind described, the plurality of 5 first souces of optical signals optically coupled with the transmitting terminals are grouped together.

In this arrangement the referencing of the first optical sources is much less difficult since the sources are grouped together, preferably at a central location. 10 Also, the terminal equipment is simplified so that only a modulator is required in the transmitting terminal. A further advantage is that the grouped components can be put on an optical integrated circuit.

Where the network is to be used solely in a 15 broadcast configuration, the transmitting terminals may be grouped together with the first sources of optical signals. In other arrangements, however, the first sources are grouped together remotely from the transmitting and receiving terminals.

20 In some cases, the selection means may comprise a wavelength selector such as a grating demultiplexer thus allowing direct detection to be achieved. Conveniently, this selection means is located adjacent the grouped first sources.

25. In another example, the selection means comprises a plurality of second sources of optical signals grouped together remotely from and optically coupled with the receiving terminals to supply tuning signals to the receiving terminals.

30 In one example, respective first and second sources of optical signals are coupled with each of the receiving and transmitting terminals. In this example, each of the optical sources coupled with the receiving terminals is preferably tunable in order to select the channel which 35 is received by the corresponding receiving terminal.

This is particularly useful in the case of for example a cable TV network where a particular receiving terminal may only receive certain channels.

In another example, the network further comprises 5 switch means for optically coupling selected ones of the first optical sources with selected transmitting terminals.

In this example, where second optical sources are provided, the switch means is conveniently adapted to 10 optically couple selected ones of the second optical sources with selected receiving terminals.

In most cases, there will be one first optical source for each transmitting terminal and, where appropriate, one second optical source for each receiving 15 terminal. In some cases, however, there may be a fewer number of optical sources than terminals. In these cases, it is preferable if the switch means is operable on a time sharing basis.

The provision of switch means provides a more 20 versatile arrangement than the previous example since each optical source can be of a fixed wavelength but may be fed to any of the receiving and transmitting terminals upon appropriate operation of the switch means. In the case where first and second optical sources are provided, 25 these are conveniently arranged in pairs of transmit and receive sources separated in wavelength by the IF frequency to enable heterodyne detection to be carried out. The switch means controls not only which pair of optical sources are selected but also the transmitting 30 and receiving terminals to which they are connected.

Since the switch means only operates on unmodulated carrier signals, if any cross-talk exists it is likely to be less troublesome than in arrangements where the information signal is being switched. If the switch 35 means is polarisation sensitive in its performance (e.g.

LiNbO₃) then there is a good prospect that the polarisation can be closely controlled because the optical source and switch means are conveniently sited together. For example, the optical sources and switch 5 means may be connected together by a short length of optical fibre which could be polarisation holding without incurring a high cost penalty.

In most practical situations, the network will include one or more transmitting/receiving stations each 10 comprising a pair of transmitting and receiving terminals. This may be, for example, a telephone network.

In this situation, it will normally be necessary to provide three optical waveguides for each station. That 15 is, one to conduct the carrier signal to the transmitting terminal, one to carry the modulated carrier signal to the cross-coupling means and one to carry a signal from the cross-coupling means to the receiving terminal.

Preferably, therefore, the or each station is 20 connected with the first and second sources via a single duplex optical waveguide, the network further comprising wavelength multiplexing means for feeding multiplexed carrier and tuning signals from the first and second optical sources to the or each single optical waveguide. 25 With this arrangement, the number of optical waveguides can be reduced to one thus simplifying the network structure and requiring the simple addition of a conventional wavelength multiplexer.

The only disadvantage of the network described above 30 arises when a large number of terminals are involved. This is because large losses may occur.

To deal with this optical amplifiers could be used. Alternatively one of the first sources may be arranged to feed a common optical carrier signal to all the 35 transmitting terminals, the network further comprising a

plurality of auxiliary receiving terminals grouped together for receiving a modulated common carrier signal from respective transmitting terminals and for controlling modulating means to modulate another carrier 5 signal associated with the transmitting terminal in response to the received modulated common carrier, the modulated associated carrier signal being fed to the cross-coupling means.

Referencing a bank of optical sources (such as 10 lasers) will add a degree of complexity and cost to an optical system, especially if the bank needs referencing to other remote banks. Hence a central referencing system is attractive. If the optical sources are sited remote from the star point (ie. the position in the 15 network where the signals are distributed) at say a parent exchange not only are many optical waveguides needed, to carry the reference signals individually to the star point but also polarisation control becomes more difficult as, for example, the performance of a LiNbO_3 20 switch is polararisation dependent. Alternatively, a wavelength multiplex might be formed to carry the signals over a single waveguide and then each carrier separated by a demultiplexer before being fed to the switch means (if present). However with closely spaced carriers this 25 too appears difficult.

Preferably, the network further comprises locking means for maintaining the wavelength of the optical signals from the first optical sources substantially constant. For example, a set of semiconductors lasers 30 may be locked at frequencies offset from a stabilised and central reference such as a HeNe. The locking could be by opto-electronic phase locked loop or by injection locking lasers with a frequency shift by optical or electrical means. Alternatively it may be possible to 35 generate a referenced set of carriers at a central point,

to transmit these as a wavelength multiplex over a tree structured waveguide network to the star points and to use them to lock a set of lasers sited at the star point.

Conveniently, therefore the locking means comprises
5 a plurality of second, remote sources of optical signals for supplying reference carrier signals with respective unique identifiers to the first sources, the network further comprising tuning control means for adjusting the output of the first sources to correspond with identified
10 reference signals.

The identifiers could be, for example, by frequency modulation of the optical sources with a set of low frequency orthogonal signals. At the star point each first source locks on to one of the reference carriers
15 and also bears the identifier imprint. This can be read and used to indicate to the local tuning control means whether retuning needs to take place. As retuning can take place before the switch means operates (when present), spurious laser signals can be prevented from
20 appearing in the signal network. Additional benefits from this type of scheme are

- 1) the first sources can be tuned to any of the incoming reference carriers and this gives an extra degree of flexibility in the network
25 operation;
- 2) as the identifiers must form an orthogonal set, it may be possible to modulate these to provide additional information channels, for example, for control signals.

30 In theory, the optical waveguides used to couple the terminals and sources may comprise multimode optical fibres. Preferably, however, monomode optical fibres are used in view of their high bandwidth potential and low power loss.

Furthermore, although in theory incoherent light could provide the optical signals it is preferable for these to be at least temporally coherent and conveniently the sources of optical signals comprise lasers.

5 In this specification the term optical is intended to refer to that part of the electro-magnetic spectrum which is generally known as the visible region together with those parts of the infra-red and ultra-violet regions at each end of the visible region which are
10 capable of being transmitted by dielectric optical waveguides such as optical fibres.

The cross-coupling means may be arranged to cause modulated carrier signals from each transmitting terminal to be fed to each receiving terminal. Other arrangements
15 are possible and indeed the cross-coupling means may be connected additionally to further cross-coupling means of other networks.

An example of a known optical network and some examples of networks in accordance with the present
20 invention will now be described with reference to the accompanying drawings, in which:-

Figure 1 illustrates a known network;

Figure 2 illustrates a portion of one example of a network according to the invention;

25 Figure 3 illustrates a portion of a second example according to the invention;

Figure 4 illustrates a portion of a third example of a network according to the invention;

Figure 5 illustrates a portion of a fourth example
30 of a network according to the invention;

Figure 6 illustrates a portion of a fifth example according to the invention; and,

Figure 7 is a block circuit diagram of the phase
35 locked loop shown in Figure 6.

The network illustrated in Figure 1 comprises a plurality of transmitters T_1-T_n each of which is coupled by respective monomode optical fibres 1 to a cross-coupler network 2. The network 2 causes a proportion of any one input to the network to appear at each of its outputs so that a wavelength multiplex is formed at each output. Each output of the network 2 is fed via respective monomode optical fibres 3 to receivers R_1-R_n .

Each transmitter includes a laser 4 which generates a temporally coherent optical carrier signal having a wavelength unique to that transmitter, the carrier signal being fed to a modulator 5 which is controlled by an information signal indicated at 6 to modulate the carrier signal in accordance with the information of the information signal. Each receiver comprises a narrow linewidth laser 7 which is added to the low level incoming signal on the optical fibre 3 in a coupler 8. The wavelengths of the two lasers 4, 7 are controlled to be either identical (for homodyne detection) or to have a small frequency difference equal to an electrical IF (for heterodyne detection). In this example, heterodyne detection is shown. A photodiode 9 is provided having a square law characteristic so that it acts as a mixer to produce a different frequency at its electrical output. A conventional electrical IF processor and detector 10 are provided to generate an output signal relating to the original information signal 6.

The laser 7 in each receiver is tunable so that it can tune in to any one of the transmission signals. Providing the channel spacing is greater than the photodiode electrical bandwidth then only a single channel is received.

In a practical system, one transmitter and one receiver would be associated in one station.

The difficulty with networks as shown in Figure 1 is that each laser 4, 7 must be referenced to the others to prevent cross-talk interference. The invention provides a solution to this by grouping together the lasers as 5 shown in Figure 2. The arrangement shown in Figure 2 is identical to that shown in Figure 1 except that each laser 4, 7 has been moved to a central location 11. This central location may be, for example, a building housing the cross-coupler 2, for example a telephone exchange.

10 In this example, each laser 4 is connected to the respective modulator 5 via a monomode optical fibre 12. Each laser 7 is connected to a centrally located coupler 13 (equivalent to the coupler 8) via a monomode optical fibre 14.

15 It will be seen from Figure 2 that the terminal equipment is simplified by centrally locating the lasers 4, 7 so that the transmitter contains only a modulator 5 while each receiver contains a photodiode 9 and an IF filter 10. The central grouping of the lasers 7 allows 20 them to be tuned at the central location.

A second example of a network according to the invention is partially illustrated in Figure 3. This example constitutes a modification of the example shown in Figure 2. In this example, instead of the lasers 4, 7 25 being associated with specific ones of the transmitters and receivers, the same number of lasers ($2n$) are connected into the network via an optical space switch 15. The space switch 15 is controlled by a means not shown to cause pairs of lasers to be connected to pairs 30 of the transmitters and receivers. Although the lasers could be tunable to achieve broadcast communication for example, this arrangement enables them to be of a fixed wavelength. In the case of heterodyne detection, the fixed wavelengths of the laser of each pair will be 35 different and separated in wavelength by the IF

frequency. In the case of homodyne detection each laser of a pair of lasers would have the same wavelength different from all other pairs.

To ensure that the wavelengths of the signals generated by the lasers remain substantially constant a laser locking system 16 is provided to control the lasers. An example of such a system is illustrated in more detail in Figure 6.

Typically, pairs of transmitters and receivers will 10 be associated in which case networks corresponding to the example shown in Figure 3 will require three optical fibres to achieve full connection between each receiving/transmitting station and the central location.

Figure 4 illustrates a portion of a third example of 15 a network according to the invention in which this problem is avoided.

In Figure 4 a receiving/transmitting station 17 is shown comprising a transmitter T_n and a receiver R_n . The transmitter and receiver are connected via monomode 20 optical fibres 18, 19 to a single duplex optical monomode fibre 20 connected to the cross-coupler 2. An output fibre 21 (corresponding to the optical fibre 3 in the previous examples) is connected from the cross-coupler 2 to the optical fibre 20. A pair of optical fibres 22, 23 25 carrying the corresponding tuning and carrier signals respectively from the space switch 15 are connected together at 24 and to the optical fibre 20 at 25. The connection of the space switch 15 to the lasers (not shown) is as in Figure 3.

30 In use, the space switch 15 selects an appropriate pair of laser output signals to constitute the tuning and carrier signals which are fed along the lines 22, 23 to the point 24 where they are wavelength multiplexed and fed onto the optical fibre 20 at 25 where further 35 wavelength multiplexing takes place. The carrier signal

is fed to the transmitter T_n where it is modulated as previously described and then the modulated carrier signal is returned along the optical fibre 20 to the cross-coupler 2. Signals output from the cross-coupler 2
5 on the line 21 are also fed in wavelength multiplexed form along the optical fibre 20 and the optical fibre 19 to the receiver R_n which retrieves the information as previously described by making use of the tuning signal.

It is believed that the arrangement shown in Figure 10 4 will demand a very high optical power budget. To reduce this problem a further network is proposed as shown in Figure 5. In this example, a number of additional lasers 26 are provided to generate respective common carrier signals which are fed via associated power
15 splitters 27 to each optical fibre 20 leading to respective sets of stations 17. (Only one additional laser 26 is shown in Figure 5) A demultiplexer 28 is provided between the optical fibres 18,19 and the optical fibre 20. The common carrier signal is externally
20 modulated by the modulator in the transmitter T_n and the modulated common carrier signal is returned along the optical fibre 20 to a respective auxiliary receiver 29 at the central location. Each auxiliary receiver 29 (R'_n) generates an electrical output on a line 30 which drives
25 a modulator 31 fed with the main carrier signal along a line 32 from the space switch 15. In another example (not shown) the modulator 31 could be controlled by optical signals from the receiver 29. As in the previous examples, the space switch 15 is fed with a range of
30 different wavelength optical signals from a bank of lasers 33. In all other respects this example is the same as the example shown in Figure 4.

The advantages of this arrangement are:

- 1) the power budget available to the cross-coupler 2 is enhanced by approximately 28dB to about 35dB
 - 5 2) if λ_T is spaced by say 10nm or more from the switched lasers, simple filter or mux/demux techniques can be used
 - 3) the extra laser L_T can be shared on a power basis
 - 10 4) now that the space switch 15 and modulators 31 are co-sited there is negligible signal delay between them. The space switch can be controlled in time to give the network a wavelength-time switching capability. Thus, for example, a wideband connection might demand the use of a pair of lasers full time. A low speed data connection on the other hand could use the selected lasers on a time shared basis.
 - 15 5) the electrical interface at the central point provides a convenient control access point.
- 20 It has been suggested in all the previous examples that each output of the cross-coupler 2 is connected to a receiver. This is not necessarily the case and, providing the loss budget permits, at least some of the outputs of the cross-coupler 2 may be linked to other cross-couplers in adjacent areas or to a remote gateway. A wavelength multiplex will automatically exist on the optical fibre and this permits a fibre efficient link network to be operated. If such linking occurs, the laser banks at different sites will need to be locked together to avoid cross-talk. To maintain the attraction of a fibre efficient network, the locking scheme needs to operate ideally over a single fibre.
- 25 30 35 An example of a locking system which could be applied to any of the examples shown in Figures 3 to 5 is illustrated in Figure 6. A bank of reference lasers 35

is provided at a position remote from the bank of lasers 33 (Figure 5) for example at a central exchange. Each reference laser output signal is fed to a locking system 34. The reference laser output signals are frequency modulated by changing the bias current frequency by a few kHz to impart a unique frequency modulation (identifier) to each signal. These identified reference signals are fed to a star coupler 36 where they are multiplexed so that identical multiplexed signals are fed along the plurality of fibres 37 to respective power splitters 38. There is one power splitter 38 for each bank of lasers 33.

Each laser 33 is positioned in a phase locked loop 39 shown in more detail in Figure 7. The reference signal is fed to a phase detector 40 whose output is fed to an IF filter 41 which feeds a laser control circuit 42. The laser control circuit 42 controls the bias current applied to the laser 33. The output signal from the laser 33 is sampled and fed back along an optical fibre 43 to a coupling point 44 where it is combined with the incoming reference signal. The output of the laser control circuit 42 is sampled at a coupling point 45, the sampled signal being fed to a comparator 46 (Figure 6). The signal fed to the comparator 46 is effectively the identifier carried on the reference signal. A microprocessor 47 stores all possible identifiers which are fed in turn to the comparator 46 and compared with the signal from the phase locked loop 39. In this way, the comparator 46 determines which reference signal the laser 33 has locked onto. If the laser 33 has locked onto an incorrect reference signal then the microprocessor 47 causes a drive circuit 48 to readjust the laser frequency to the correct reference frequency. It should be understood that there will be a separate phase locked loop 39, comparator 46, and drive circuit 48 for

each laser 33 but the microprocessor 47 can be common to all the comparators 46.

The laser locking systems 16 and 34 may take any convenient form. Examples are discussed in "The Application of Coherent Optical Techniques to Broadband Networks" by G R Hill and I W Stanley, 2nd International Technical Symposium on Optical and Electrooptical Science and Engineering at Cannes, November 1985.

In all these examples various modulation techniques may be used.

In a link to a terminal there are likely to be both fixed and varying changes in the polarisation of a received optical signal if polarisation holding fibre is to be avoided. The standard modulation methods of ASK, PSK, and FSK of the optical E field may be used. These all require polarisation correction to be applied before the heterodyne signal is combined with the information signal to ensure reliable performance.

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CLAIMS

1. An optical network comprising a plurality of transmitting and receiving terminals; cross-coupling means, the transmitting and receiving terminals being optically coupled with the cross-coupling means whereby modulated carrier signals transmitted from the transmitting terminals are fed to the receiving terminals via the cross-coupling means; selection means associated with each receiving terminal to select the modulated carrier signal to be received; and a plurality of first sources of optical signals grouped together and optically coupled with the transmitting terminals to supply carrier signals to the transmitting terminals.
2. A network according to claim 1, wherein the first sources are grouped together remotely from the transmitting and receiving terminals.
3. A network according to claim 1 or claim 2, wherein the selection means comprises a plurality of second sources of optical signals grouped together remotely from and optically coupled with the receiving terminals to supply tuning signals to the receiving terminals.
4. A network according to any of claims 1 to 3, further comprising switch means for optically coupling selected ones of the first optical sources with selected transmitting terminals.
5. A network according to claim 4, when dependant on claim 3, wherein the switch means is adapted to optically couple selected ones of the second optical sources with selected receiving terminals.
6. A network according to claim 4 or claim 5, wherein the switch means is operable on a time sharing basis.
7. A network according to at least claim 3, the network including one or more transmitting/receiving stations each comprising a pair of transmitting and receiving terminals, the or each station being connected with the

first and second sources via a single duplex optical waveguide; and wavelength multiplexing means for feeding multiplexed carrier and tuning signals from the first and second optical sources to the or each single optical
5 waveguide.

8. A network according to any of claims 1 to 6, wherein one of the first sources is arranged to feed a common optical carrier signal to all the transmitting terminals, the network further comprising a plurality of auxiliary
10 receiving terminals grouped together for receiving a modulated common carrier signal from respective transmitting terminals and for controlling modulating means to modulate another carrier signal associated with the transmitting terminal in response to the received
15 modulated common carrier, the modulated associated carrier signal being fed to the cross-coupling means.

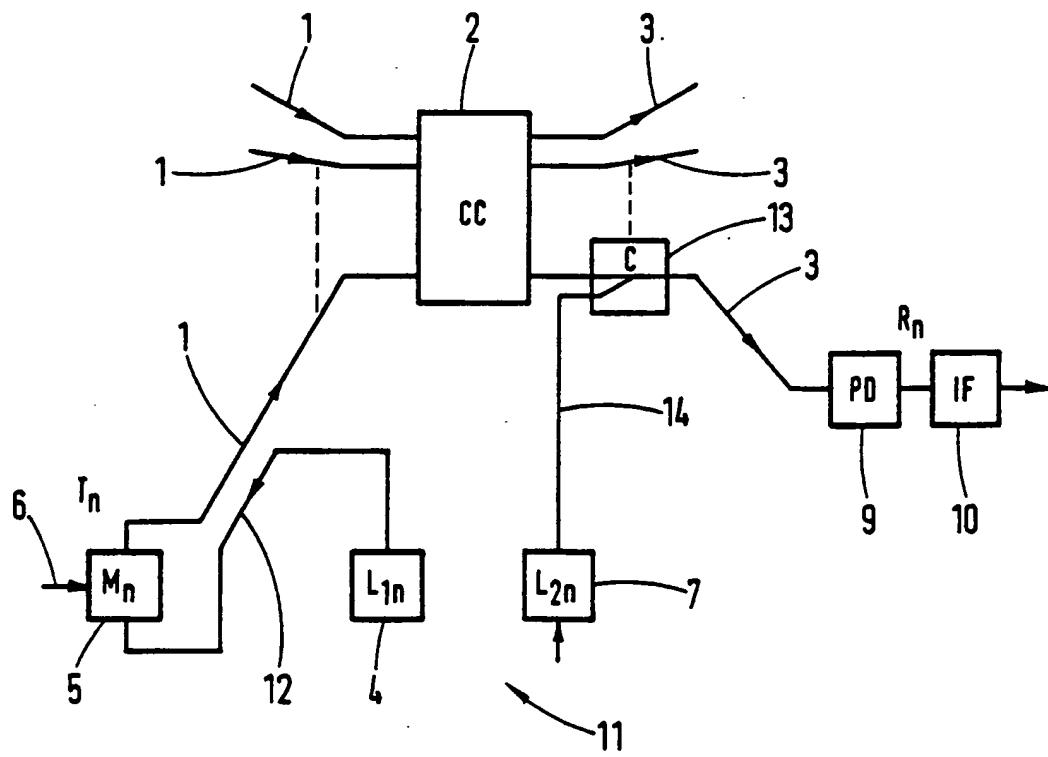
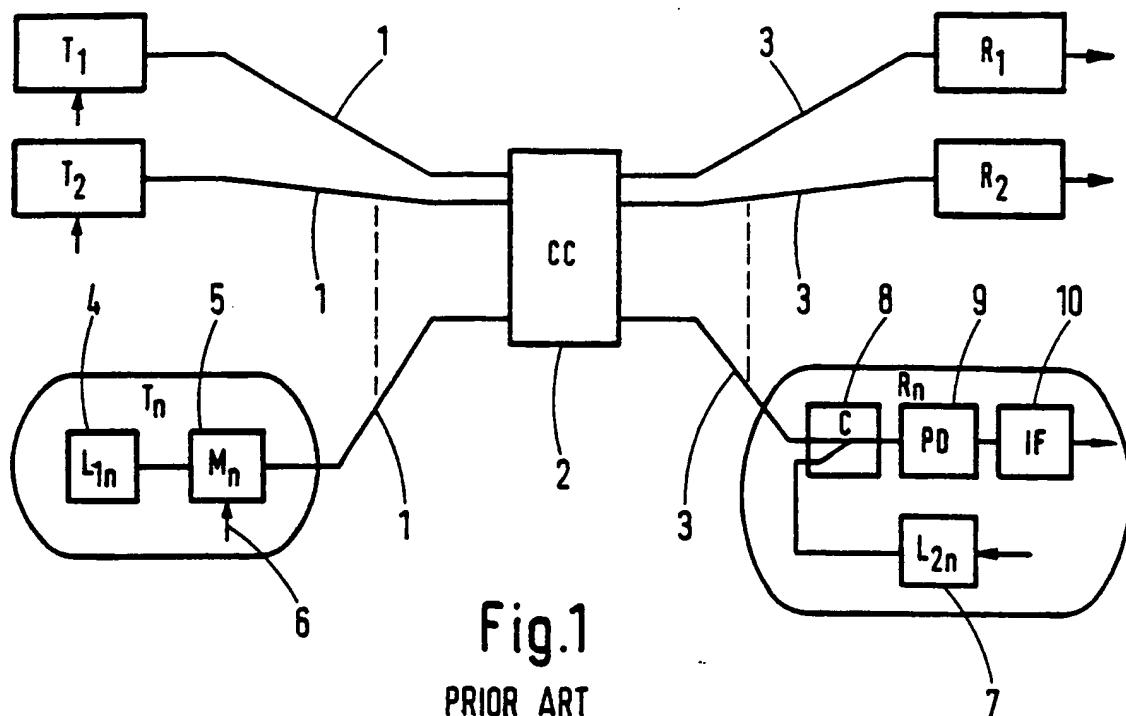
9. A network according to any of the preceding claims, further comprising locking means for maintaining the wavelength of the optical signals from the optical
20 sources substantially constant.

10. A network according to claim 9, wherein the locking means comprises a plurality of second, remote sources of optical signals for supplying reference carrier signals with respective unique identifiers to the first sources,
25 the network further comprising tuning control means for adjusting the output of the first sources to correspond with identified reference signals.

11. A network according to any of the preceding claims, wherein monomode optical fibres are used to optically
30 couple the terminals and optical sources.

12. An optical network substantially as hereinbefore described with reference to any of the examples shown in Figures 2 to 6 of the accompanying drawings.

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**Fig. 2**

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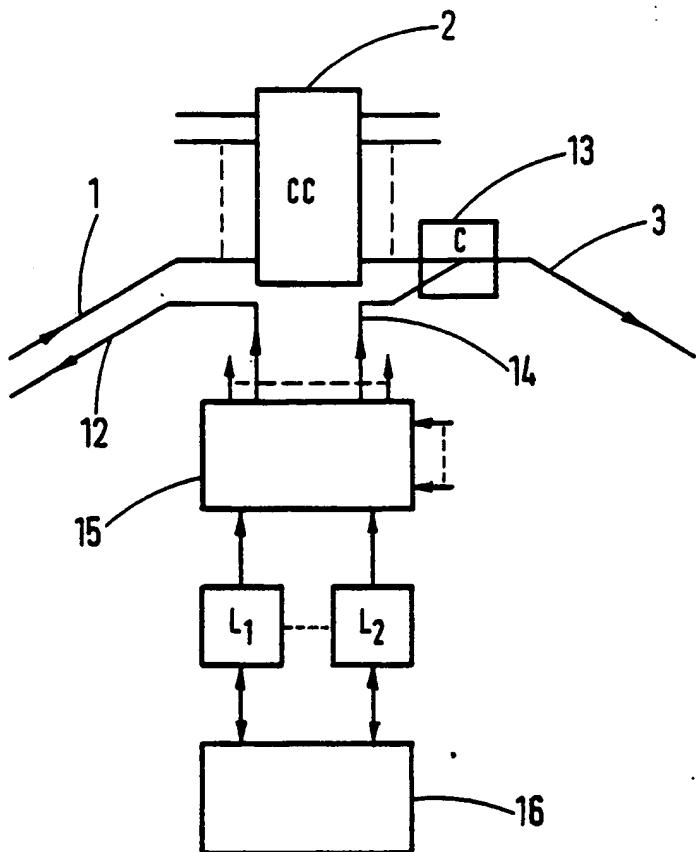


Fig.3

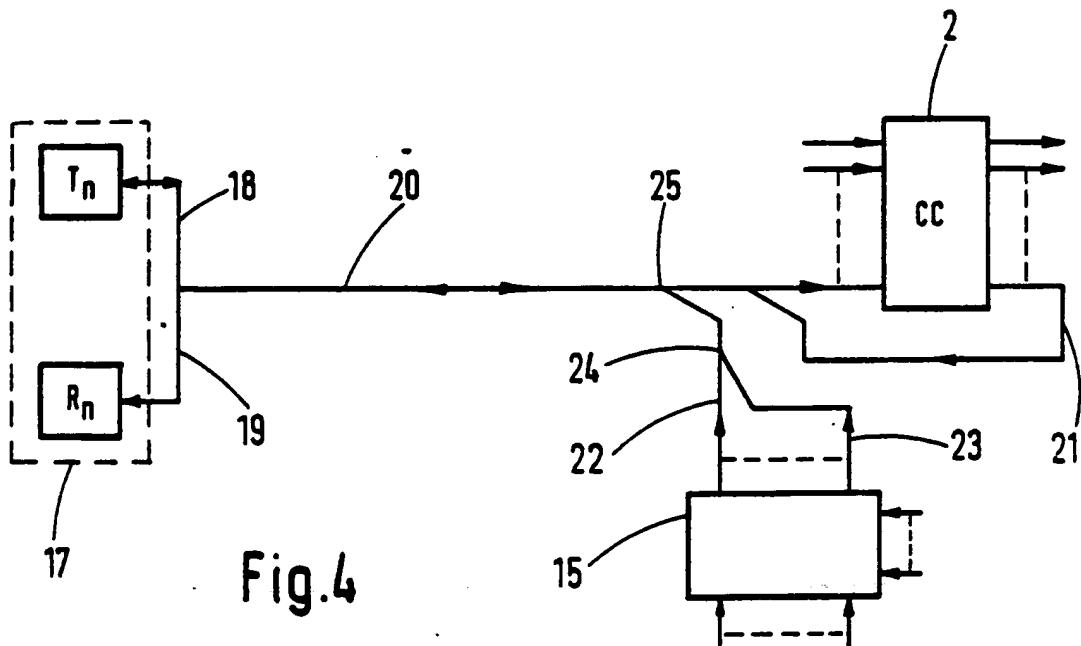


Fig.4

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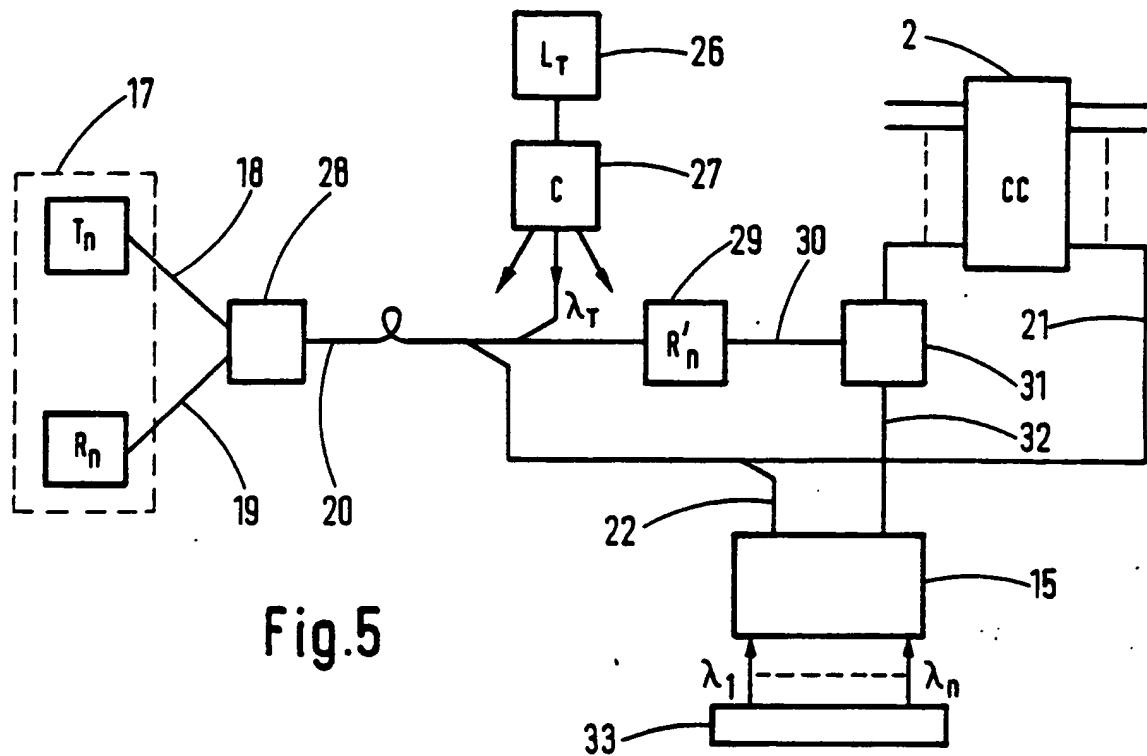


Fig. 5

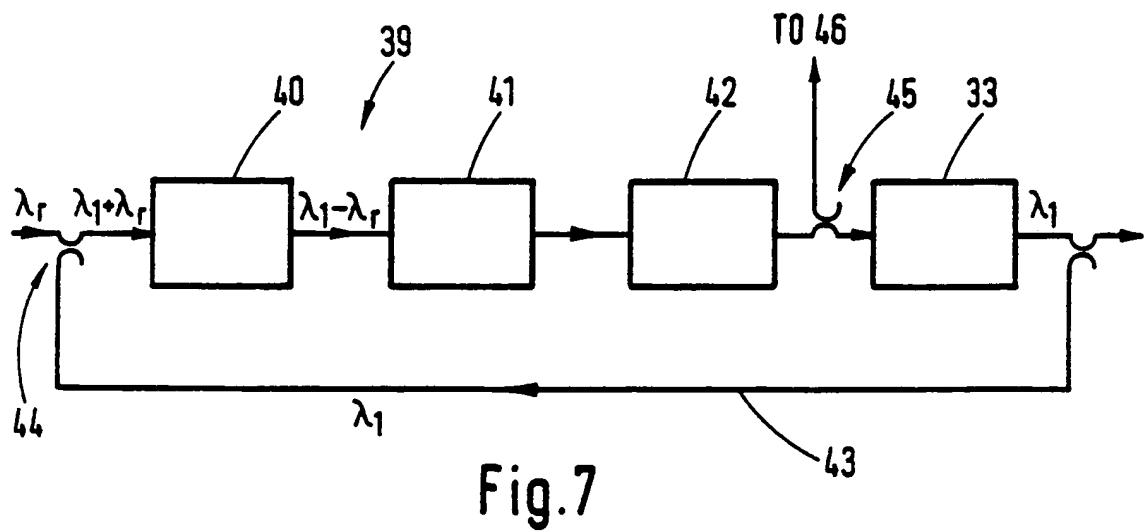


Fig. 7

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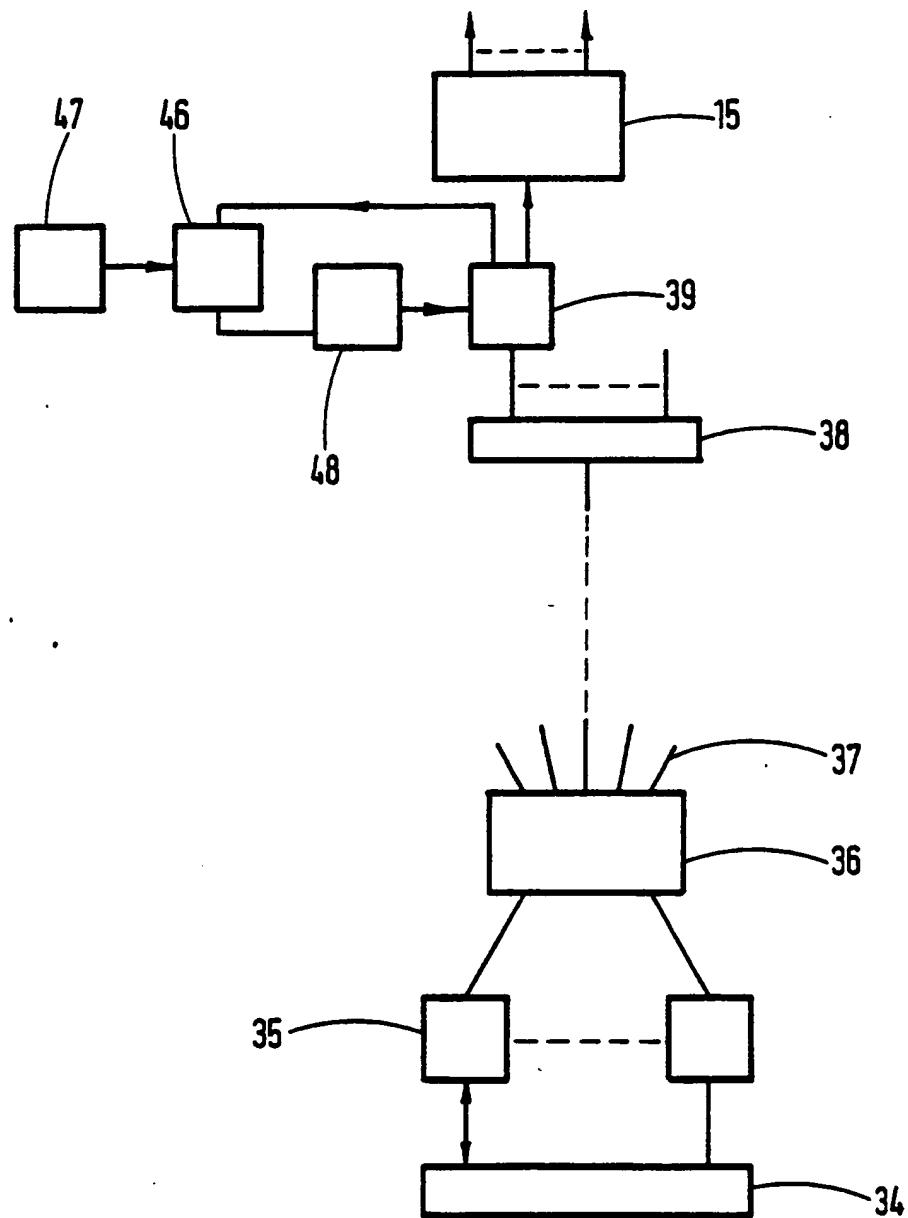


Fig.6

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 86/00017

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC
 IPC⁴ H 04 Q 11/02; H 04 B 9/00; H 04 J 15/00

II. FIELDS SEARCHED

Minimum Documentation Searched ?

Classification System	Classification Symbols
IPC ⁴	H 04 Q H 04 B H 04 J

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched *

III. DOCUMENTS CONSIDERED TO BE RELEVANT*

Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	EP, A, 0077292 (HEINRICH-HERTZ) 20 April 1983, see page 6, line 21 - page 7, line 3; page 11, lines 6-9 --	1-3
P,X	EP, A, 0131818 (INT. STAND. ELECTRIC) 23 January 1985, see page 4, lines 4-14 & AU, A, 29872/84 3 January 1985 --	1-3
A	DE, A, 2436265 (LICENTIA) 12 February 1976, see pages 22,23; figures 9,10 --	1-6
A	Frequenz, volume 36, no. 12, December 1982, Berlin, (DE) M. Rocks et al.: "Optische multiplexsysteme in der optischen Nachrichtentechnik", pages 319-327, see page 324, paragraphs 3.1.1 and 3.1.2 -----	1-3

* Special categories of cited documents: 10

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

11th March 1986

Date of Mailing of this International Search Report

09 APR 1986

International Searching Authority

EUROPEAN PATENT OFFICE

Signature of Authorized Officer

M. VAN MOL

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO. PCT/GB 86/00017 (SA 11847)

This Annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report. The members are as contained in the European Patent Office EDP file on 26/03/86

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A- 0077292	20/04/83	JP-A- 58129847 DE-A- 3237845 US-A- 4530084 CA-A- 1199074	03/08/83 11/08/83 16/07/85 07/01/86
EP-A- 0131818	23/01/85	GB-A- 2142796 AU-A- 2987284 JP-A- 60037847	23/01/85 03/01/85 27/02/85
DE-A- 2436265	12/02/76	None	